Pulsational instability in massive stars: implications for SN and LBV progenitors

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Outline

- RSG are unstable to pulsation
- Pulsational properties
- Pulsationally enhanced mass loss
- Implications for SN progenitors
- Implications for SN impostors / LBV-like eruptions

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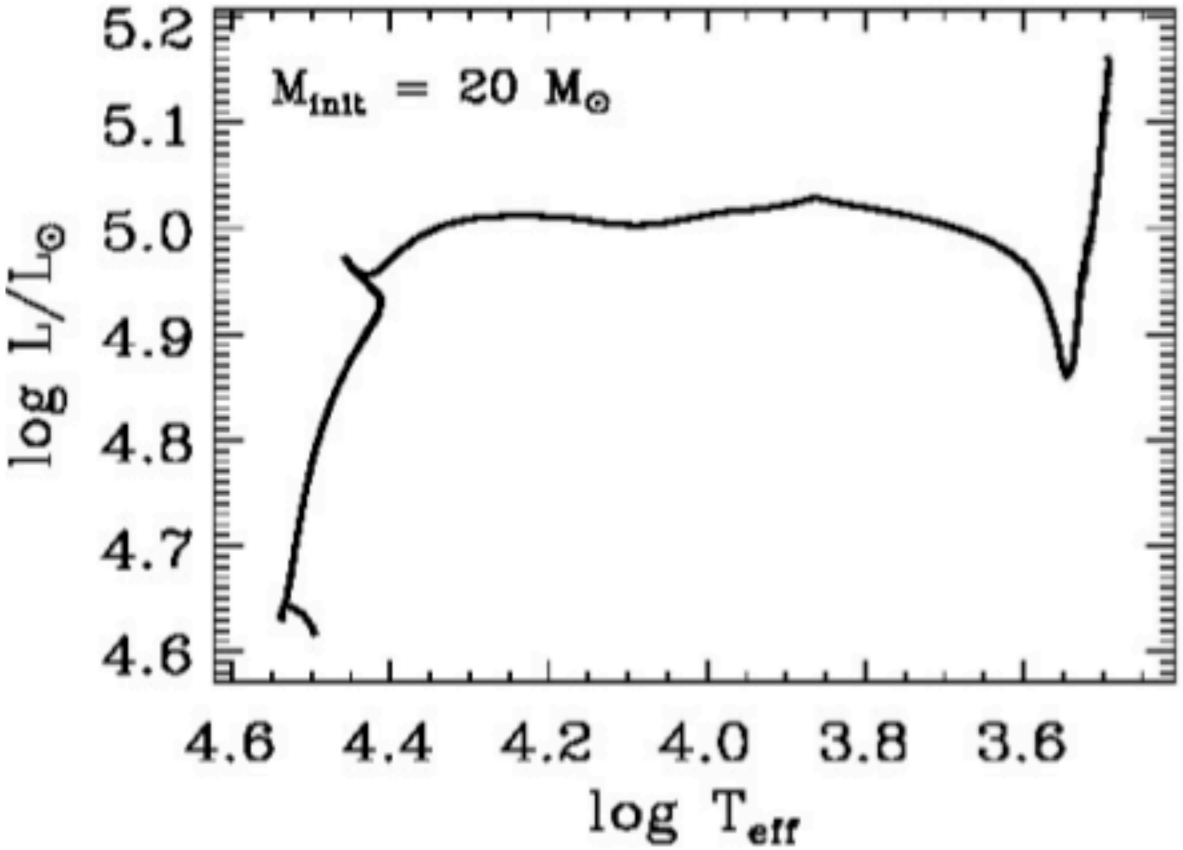
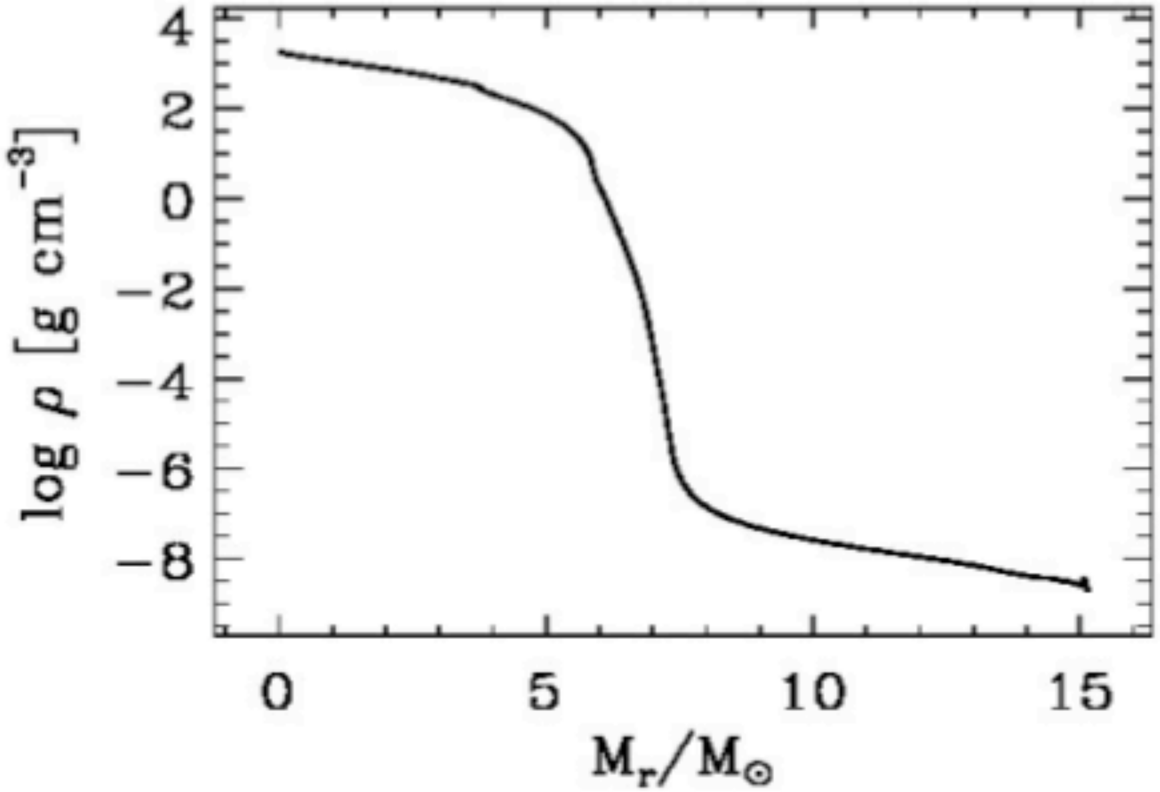
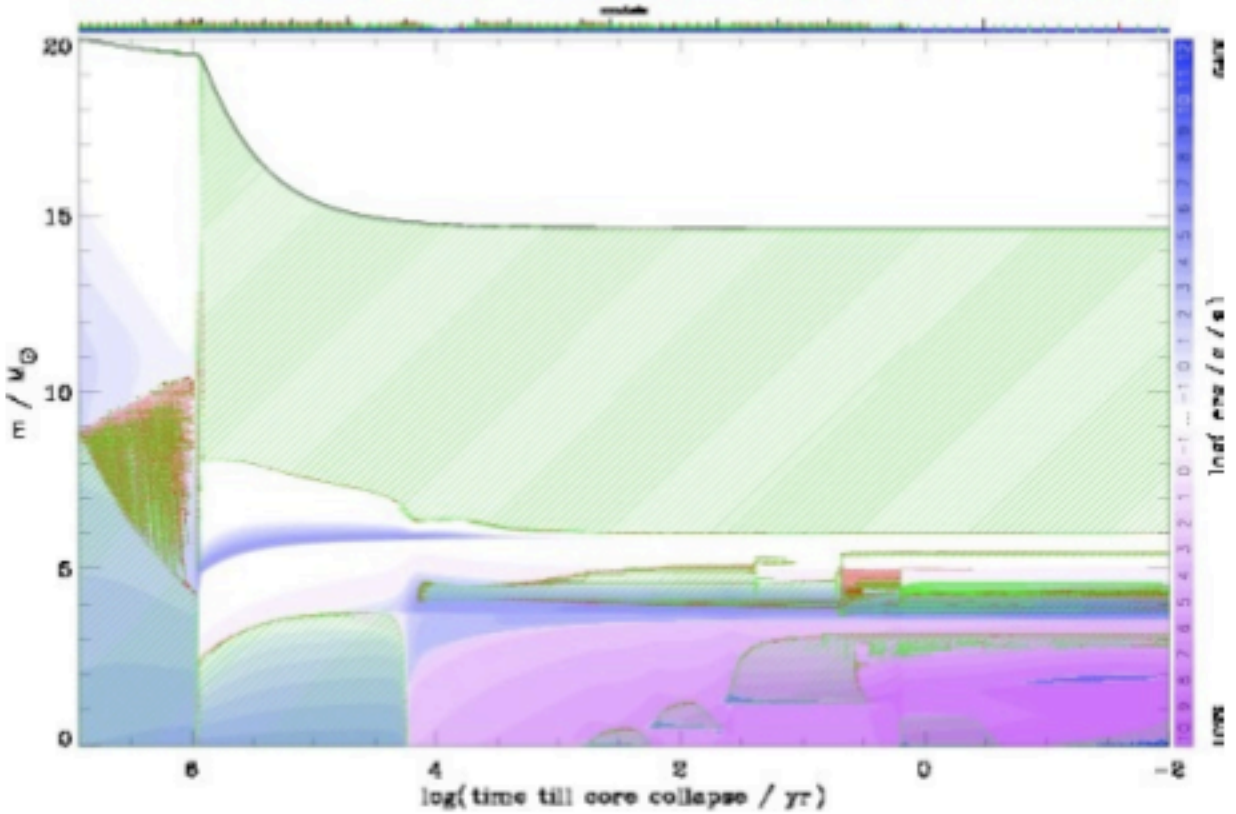
NB: Work in progress - Very preliminary results

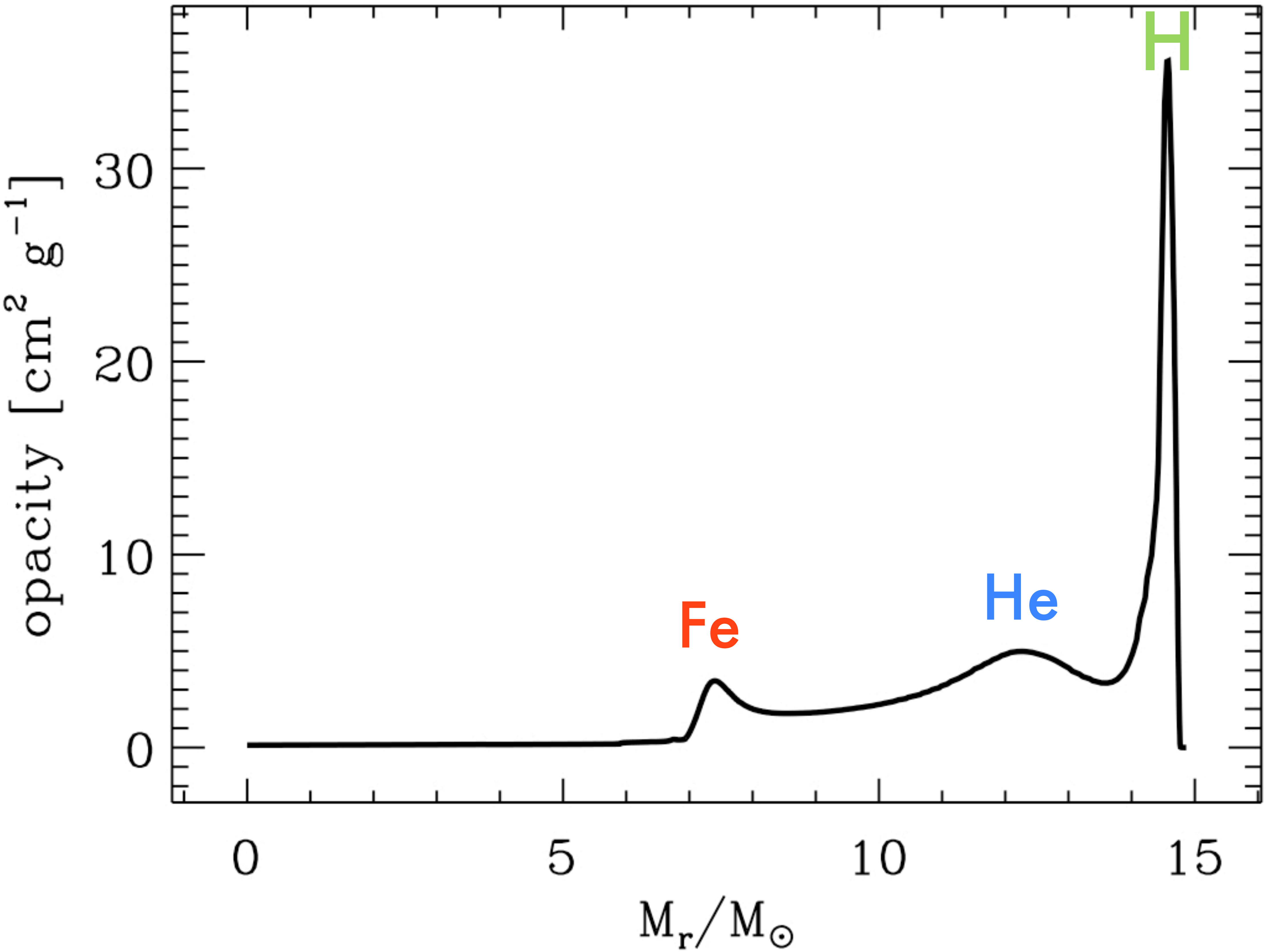
Properties of a RSG







Opacity inside a RSG



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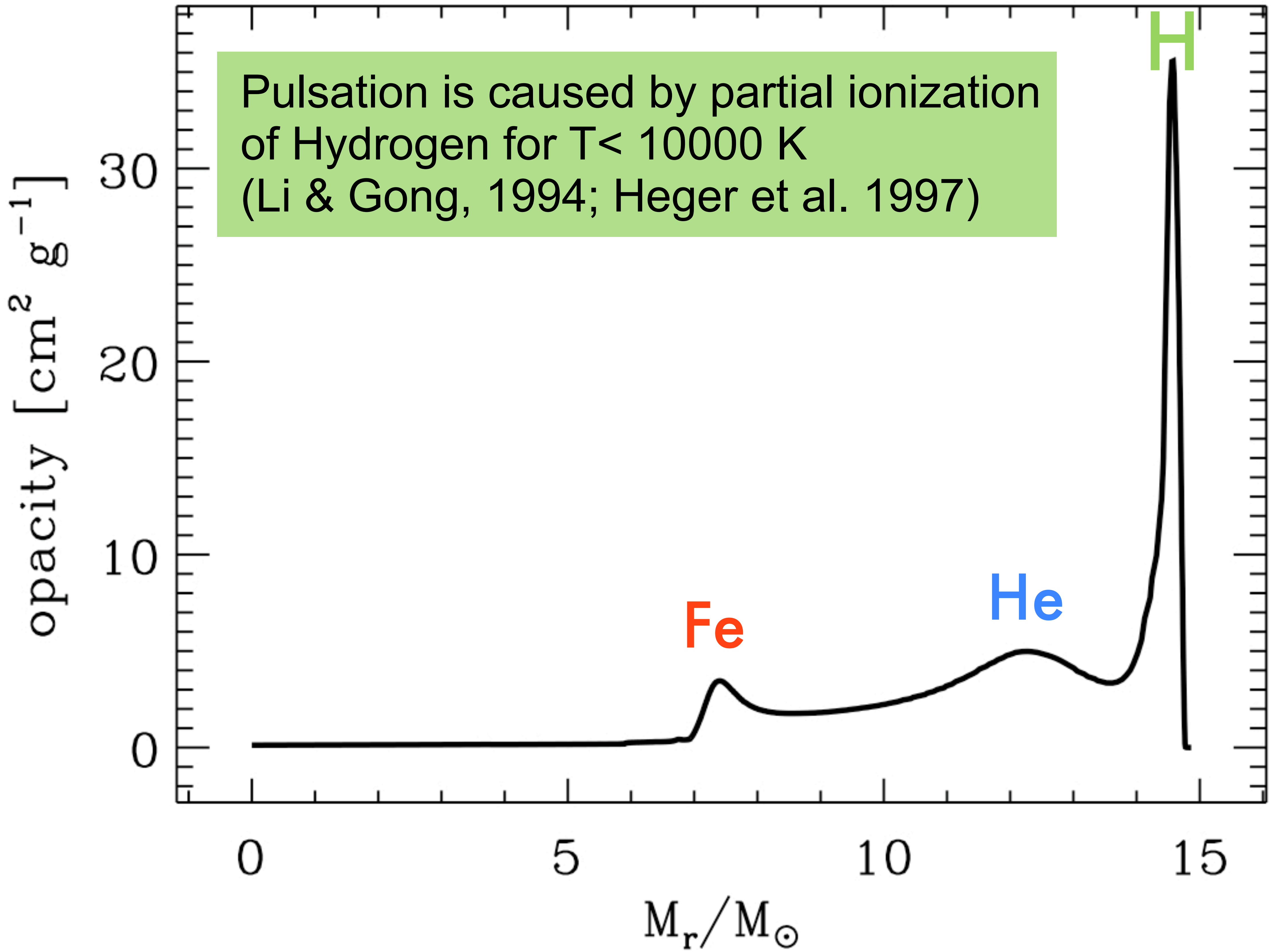
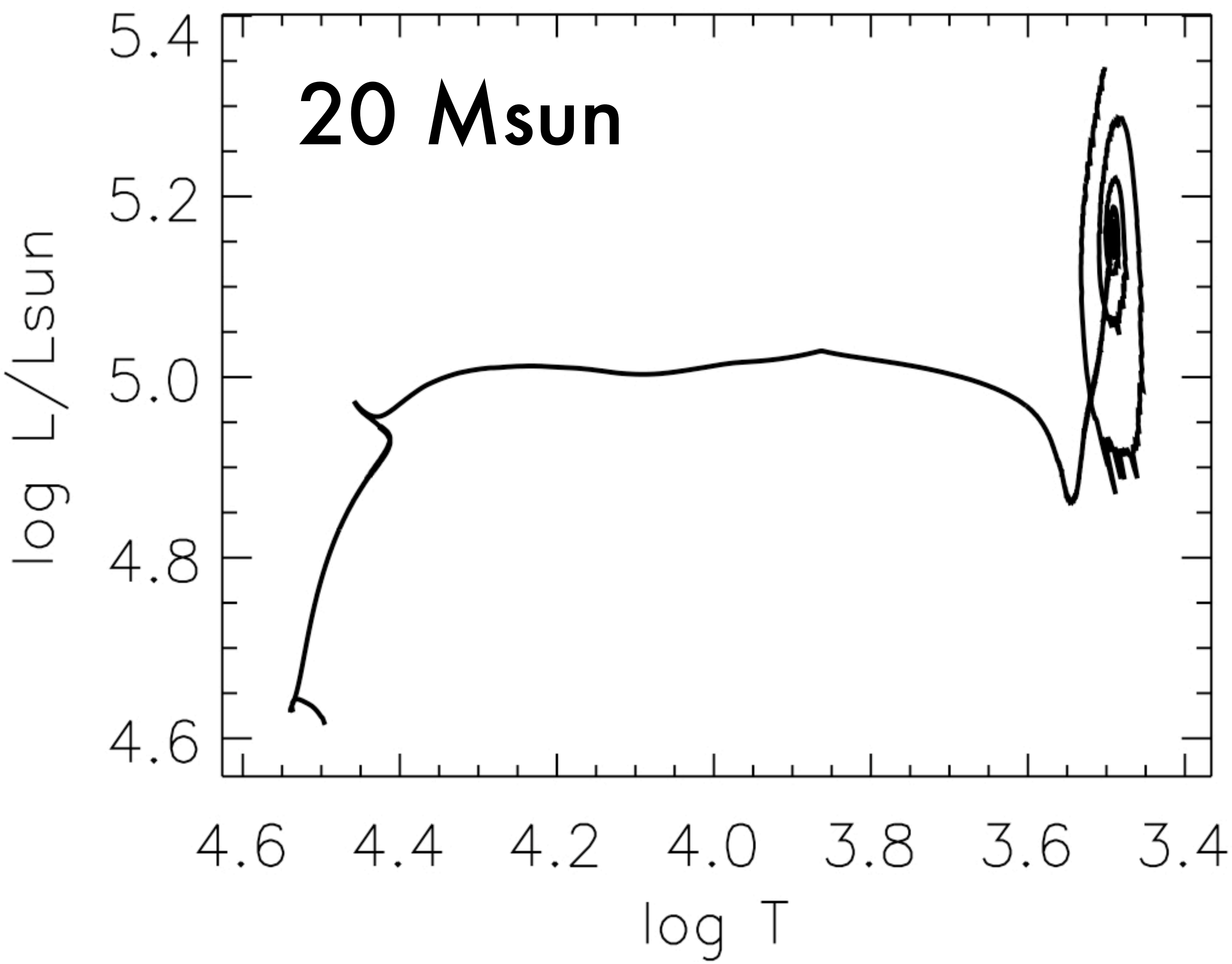


Non-linear Calculations

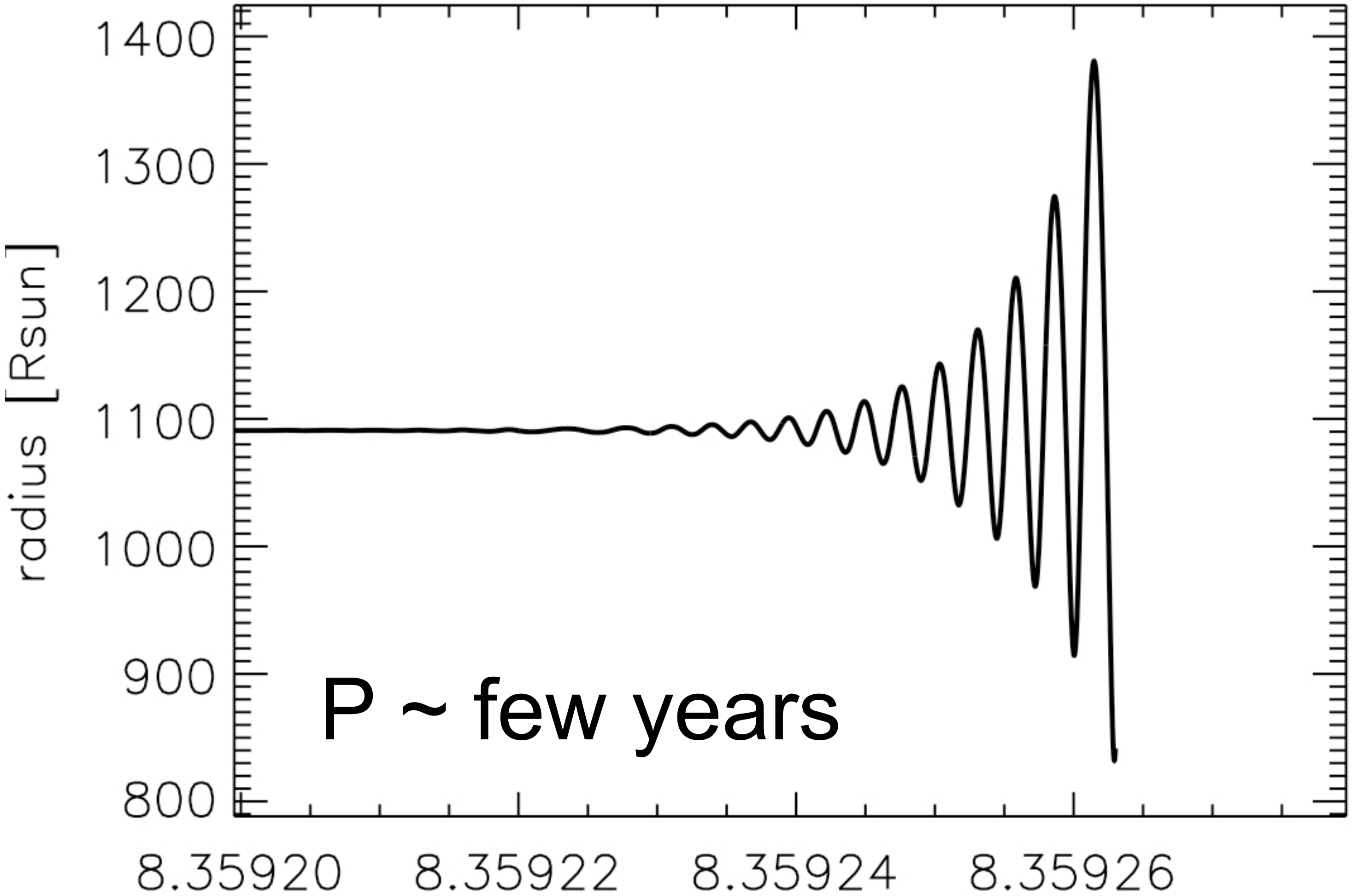
- With the **hydrodynamic stellar evolution code**, one can detect pulsation in a RSG model, if we use a sufficiently small time step at a given evolutionary stage.

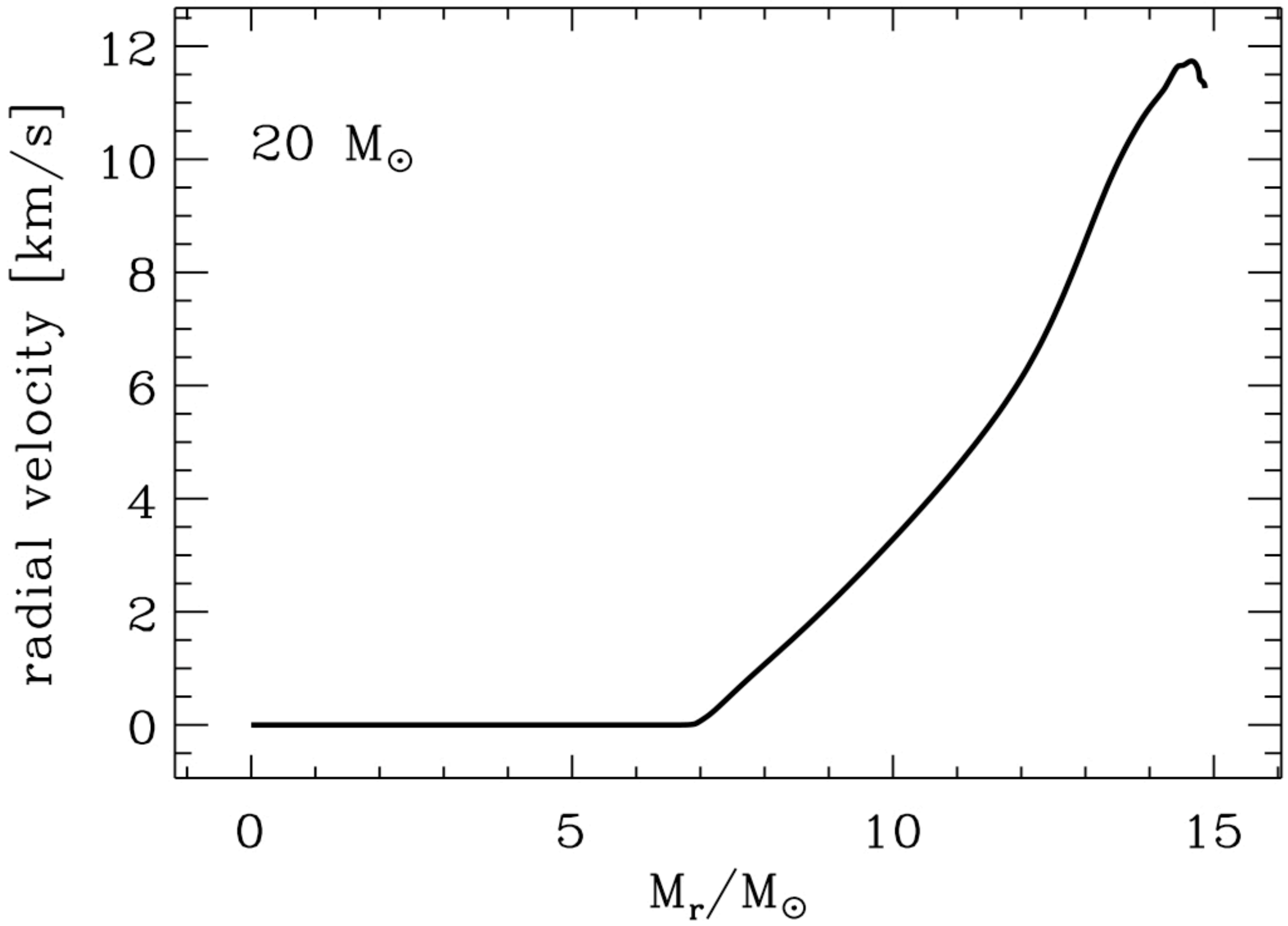
- The advantage of using the stellar evolution code, over linear stability analysis: one can investigate pulsation even when the star is thermally unstable, or when the evolutionary time is very short.

- Caveat: the **implicit solver strongly damps out pulsation**.



Pulsation properties



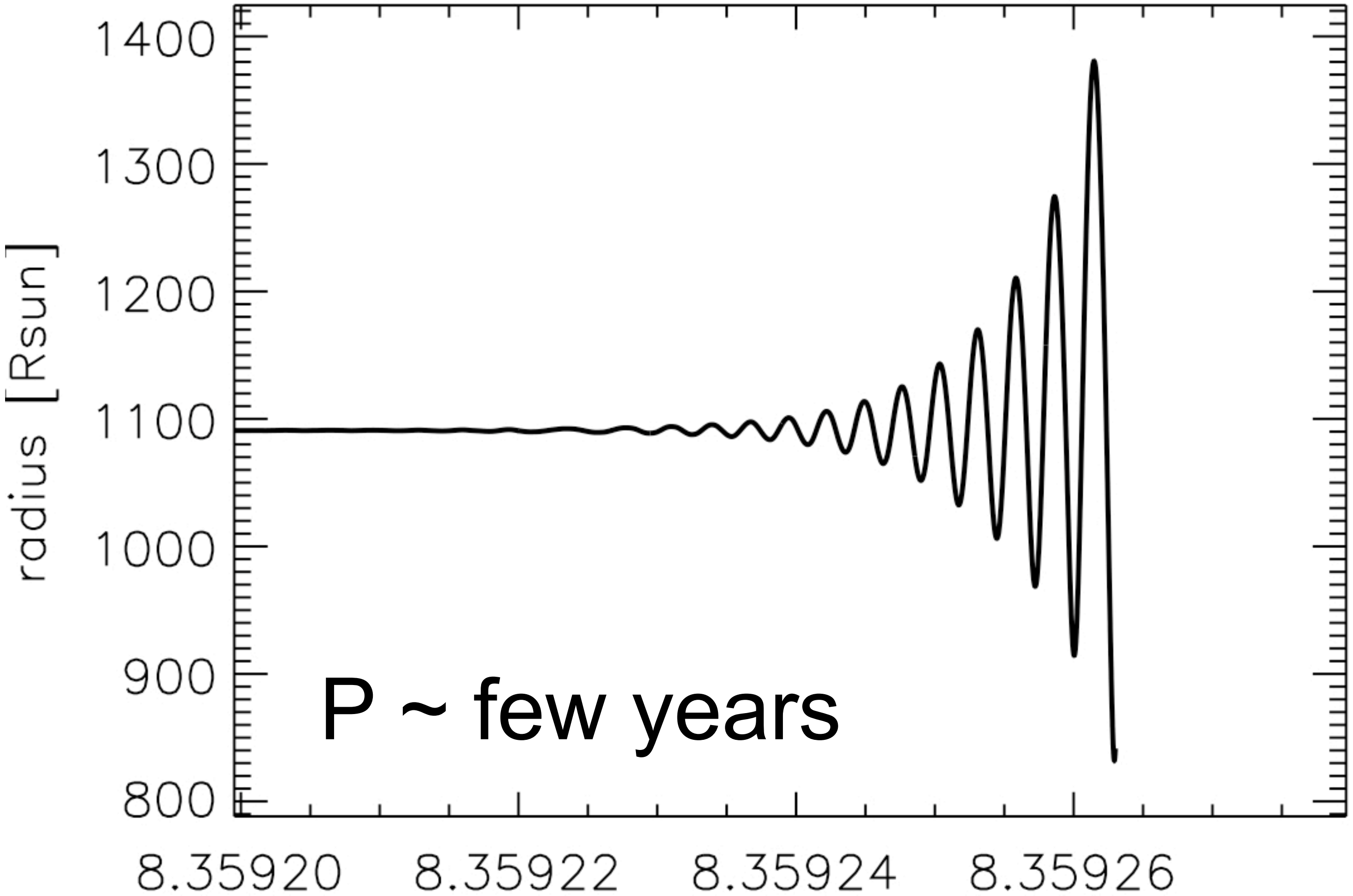


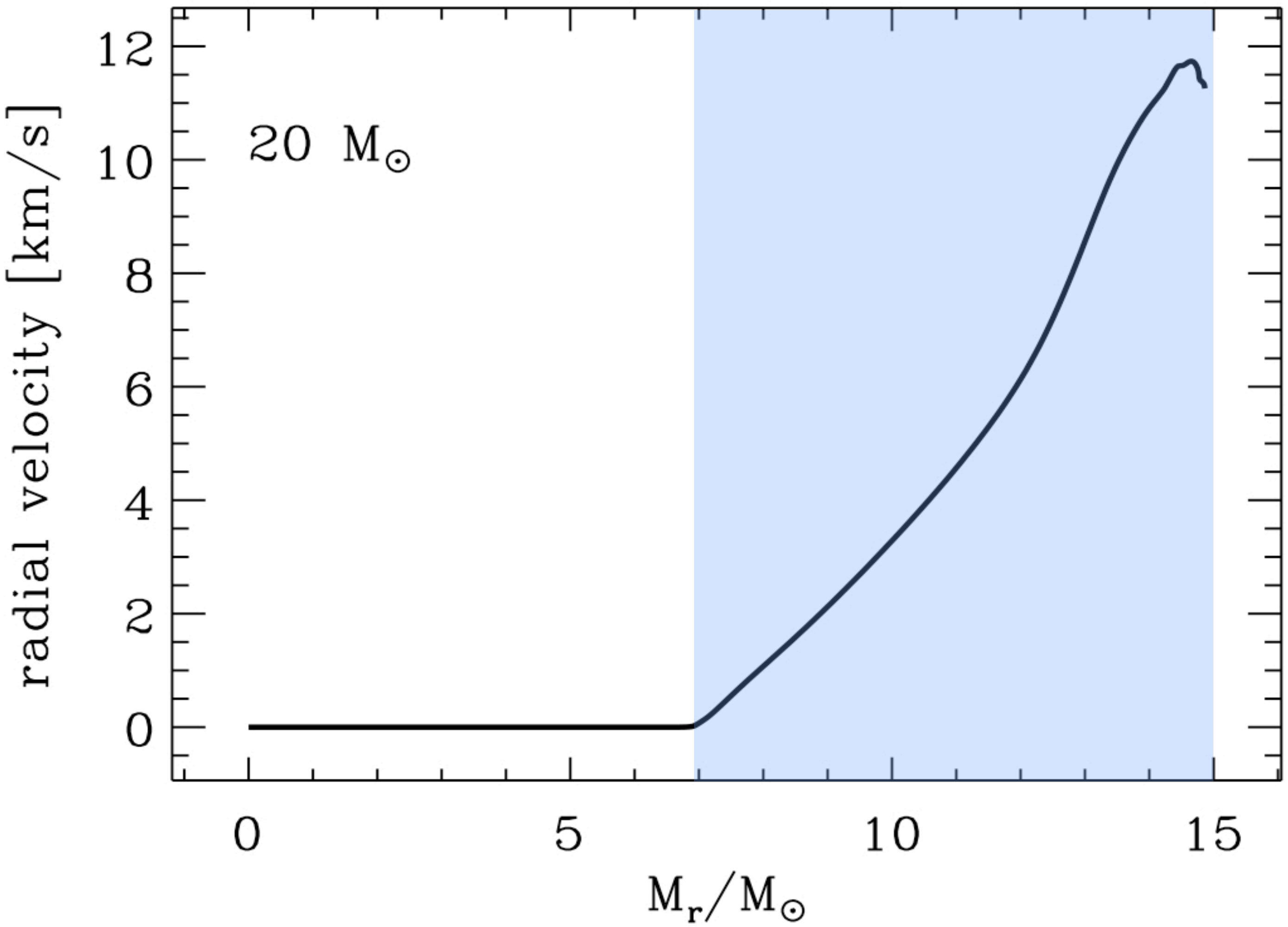
Pulsation can provide a large amount of momentum into the outermost layers of a RSG

=> Superwinds ?

If so we expect a runaway process (since the strength of pulsation is controlled by the ratio L/M)

Pulsation properties





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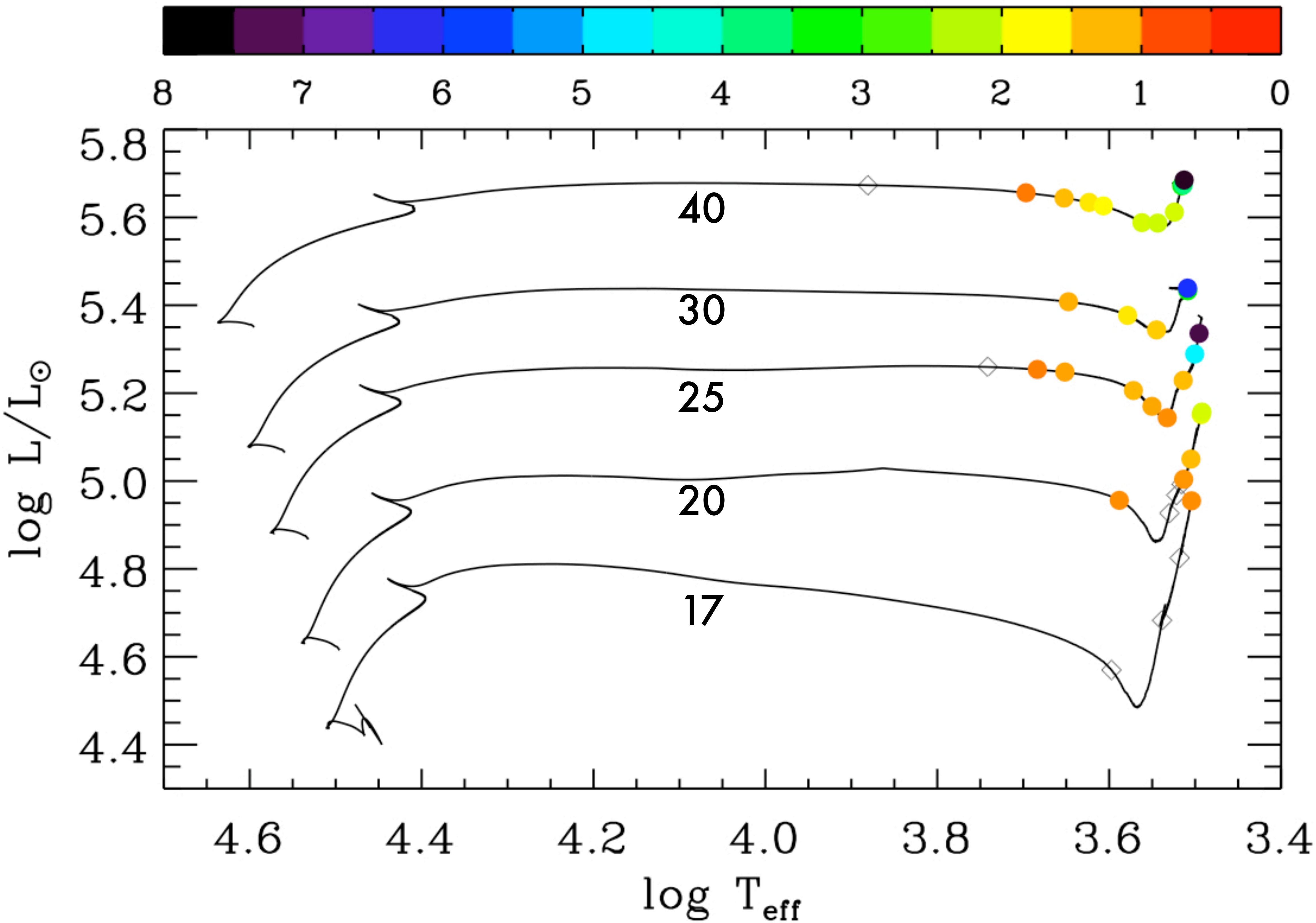
Models unstable to strong pulsation



The ‘RSG Problem’

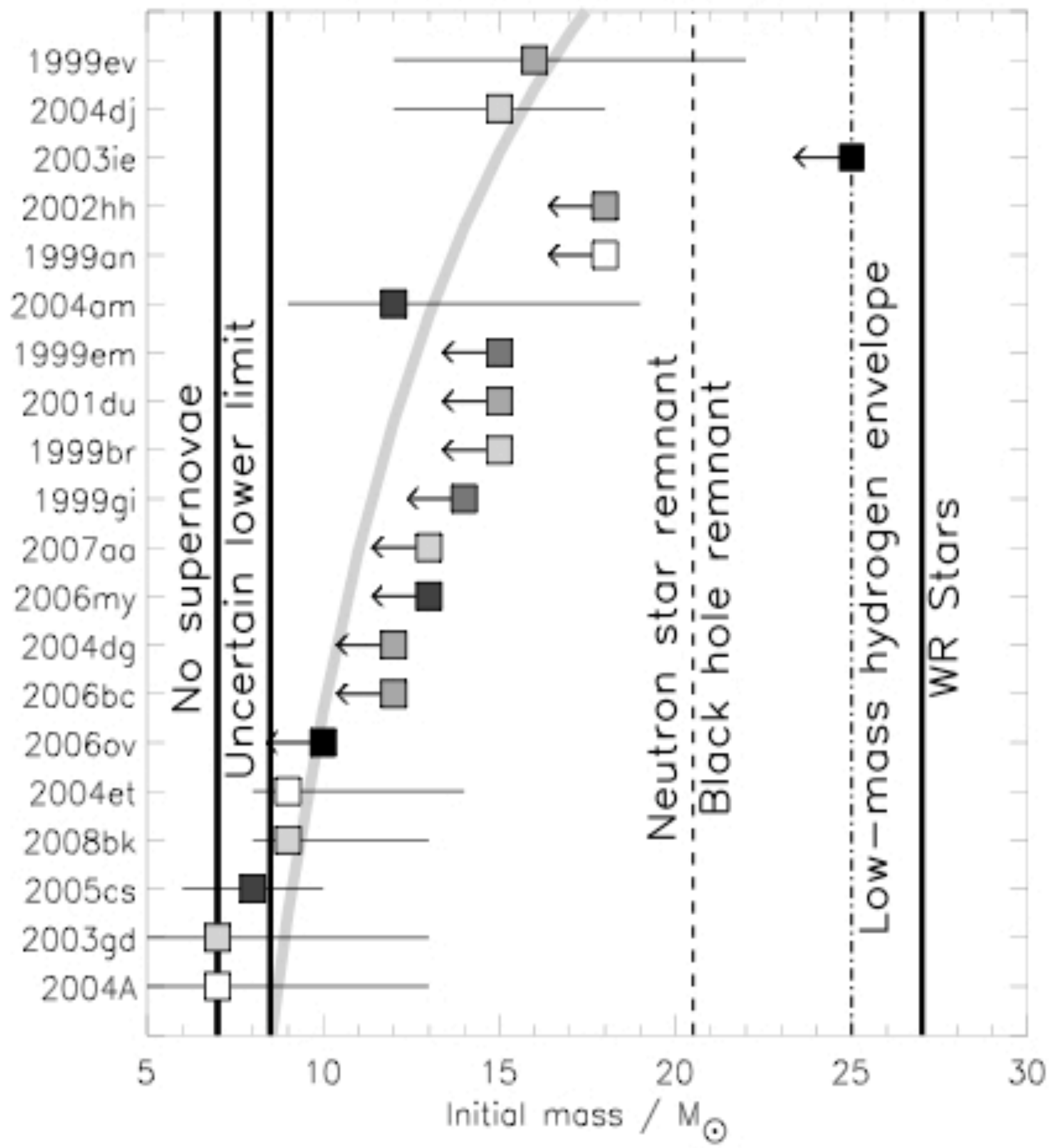
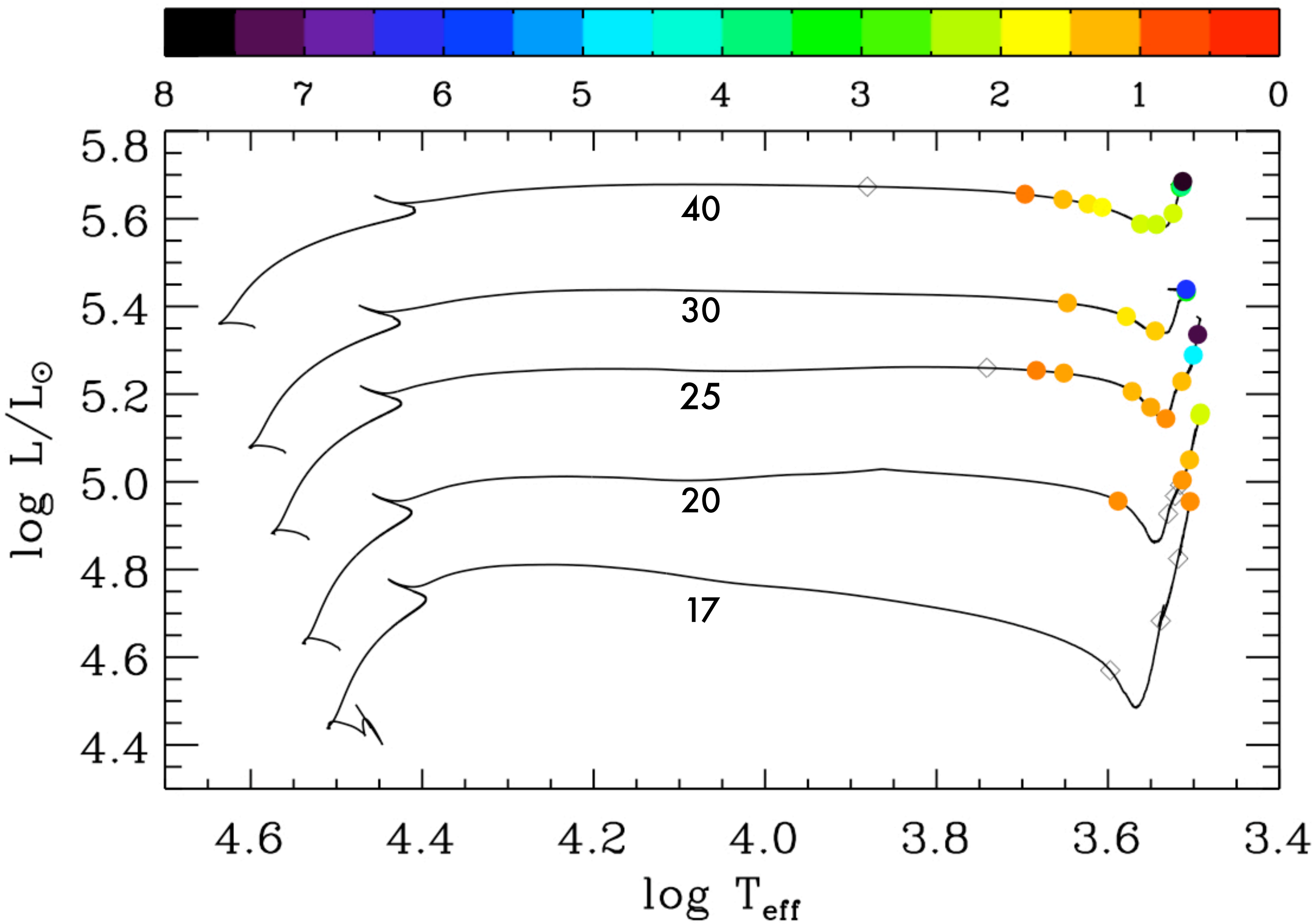


Figure 8. The initial masses of all our type II-P progenitor stars, compared with our theoretical limits for production of supernovae of different types and type of compact remnant. The box symbols are shaded on a metallicity scale, the lighter the shade the lower the metallicity, with the values taken from Table 2.

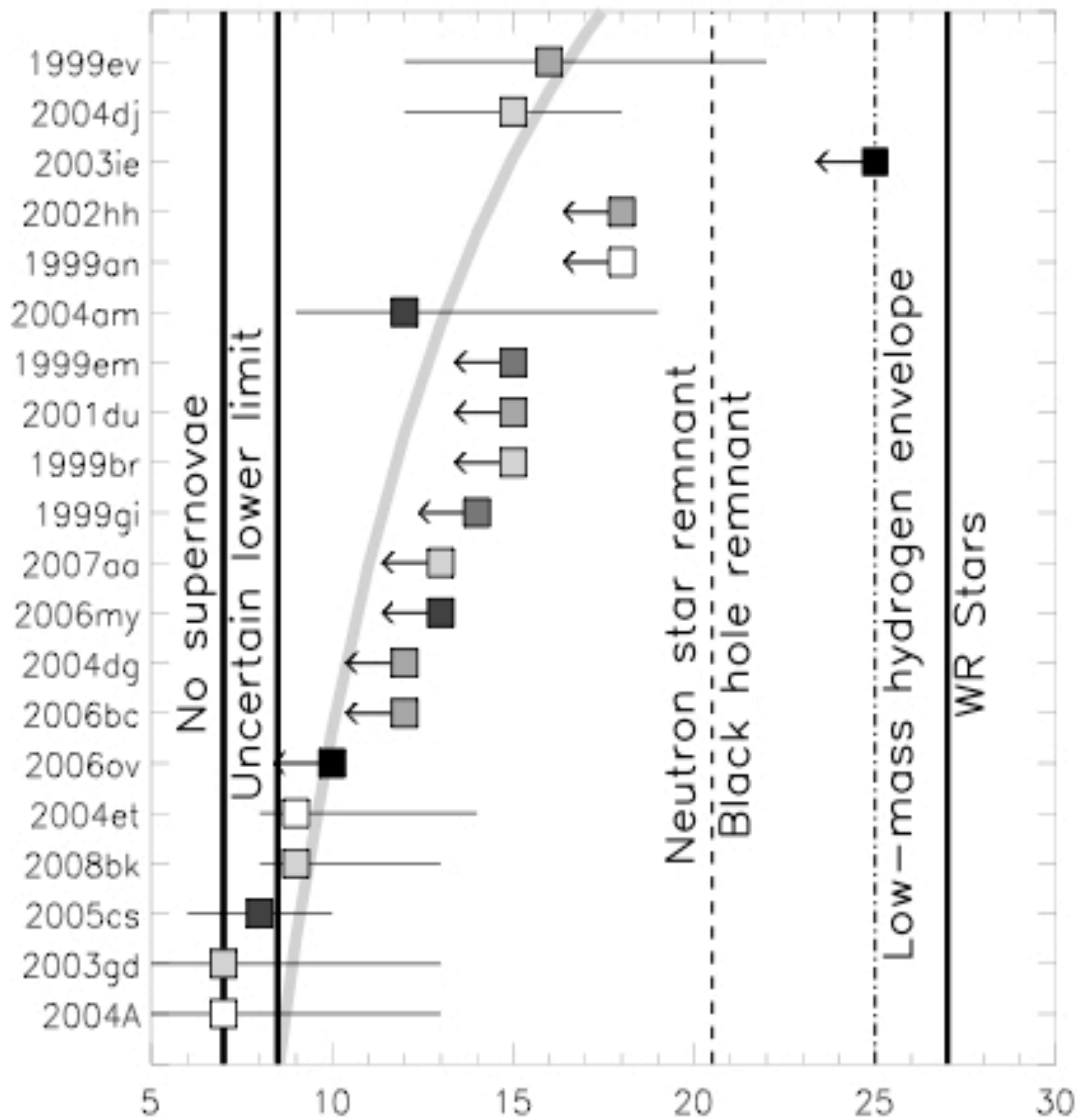


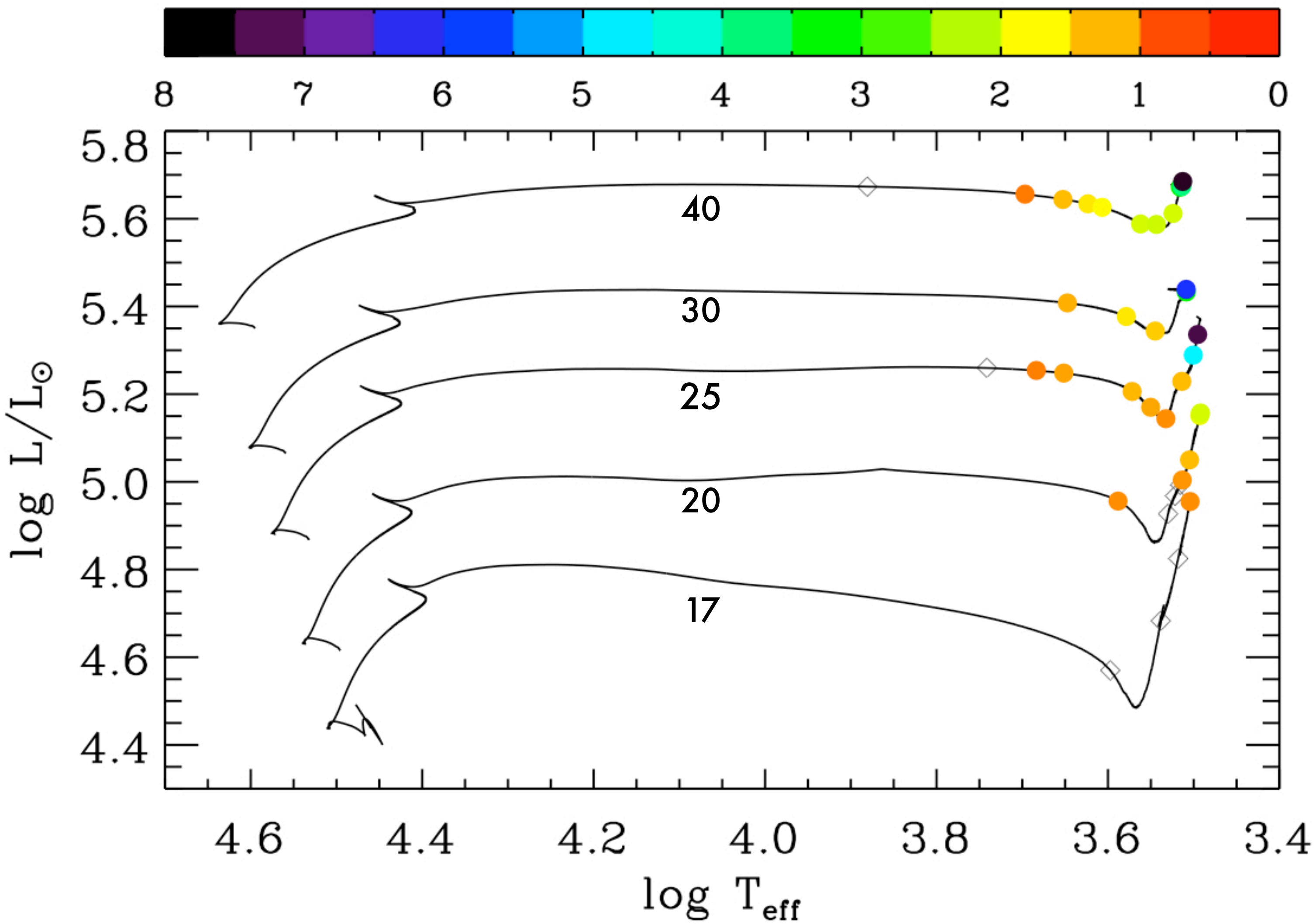
No type IIP progenitor is found for M_{ini} > 17 Msun

(Smartt et al. 2009)

Can Pulsation explain this?

The 'RSG Problem'





Lack of yellow supergiants in M31 with mass > 20 M_{sun}
(Drout, Massey, Meynet et al. 2009)

Evidence for Superwind?

No type IIP progenitor is found for M_{ini} > 17 Msun
(Smartt et al. 2009)

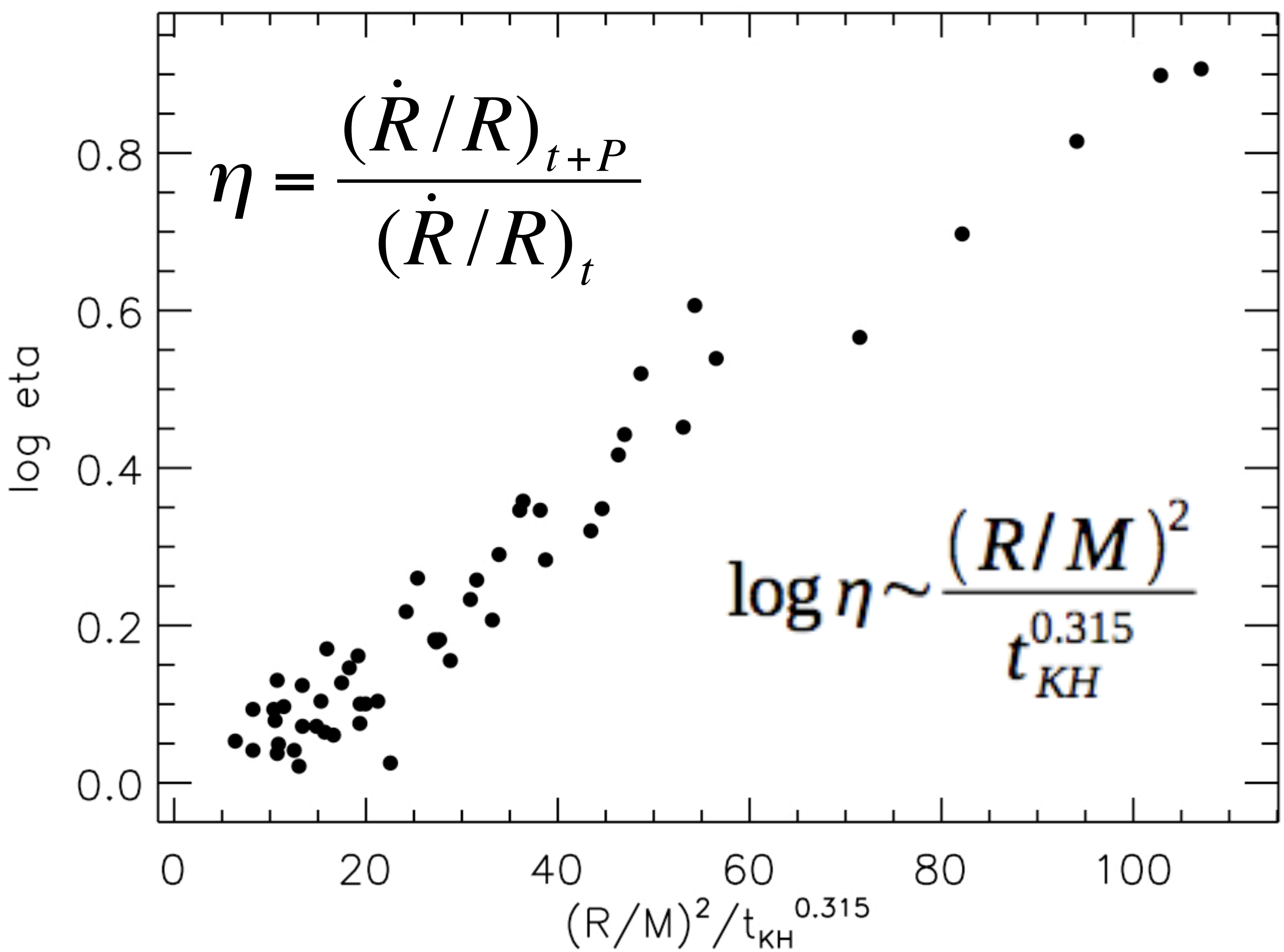
Can Pulsation explain this?

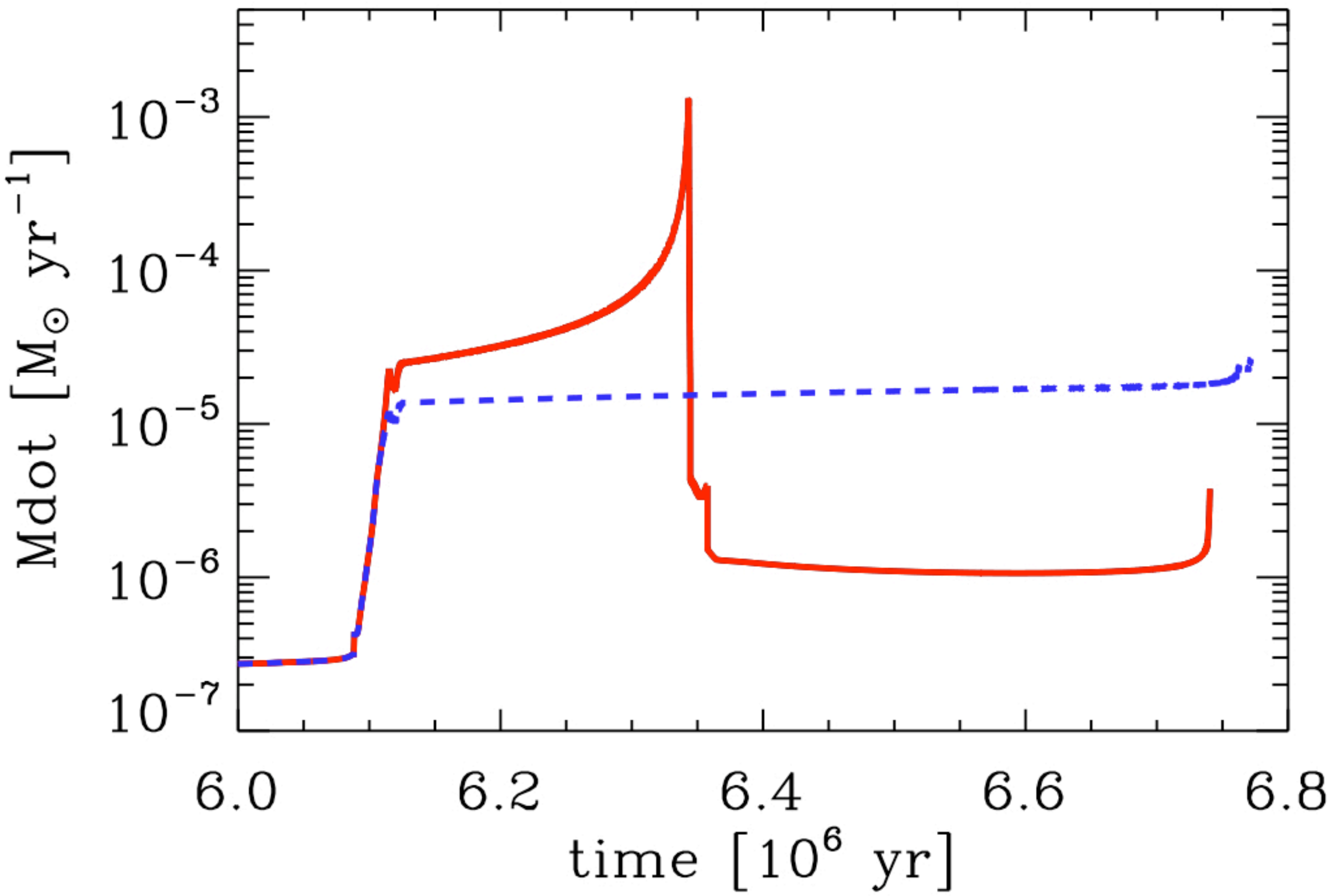
Pulsation Growth-Rate

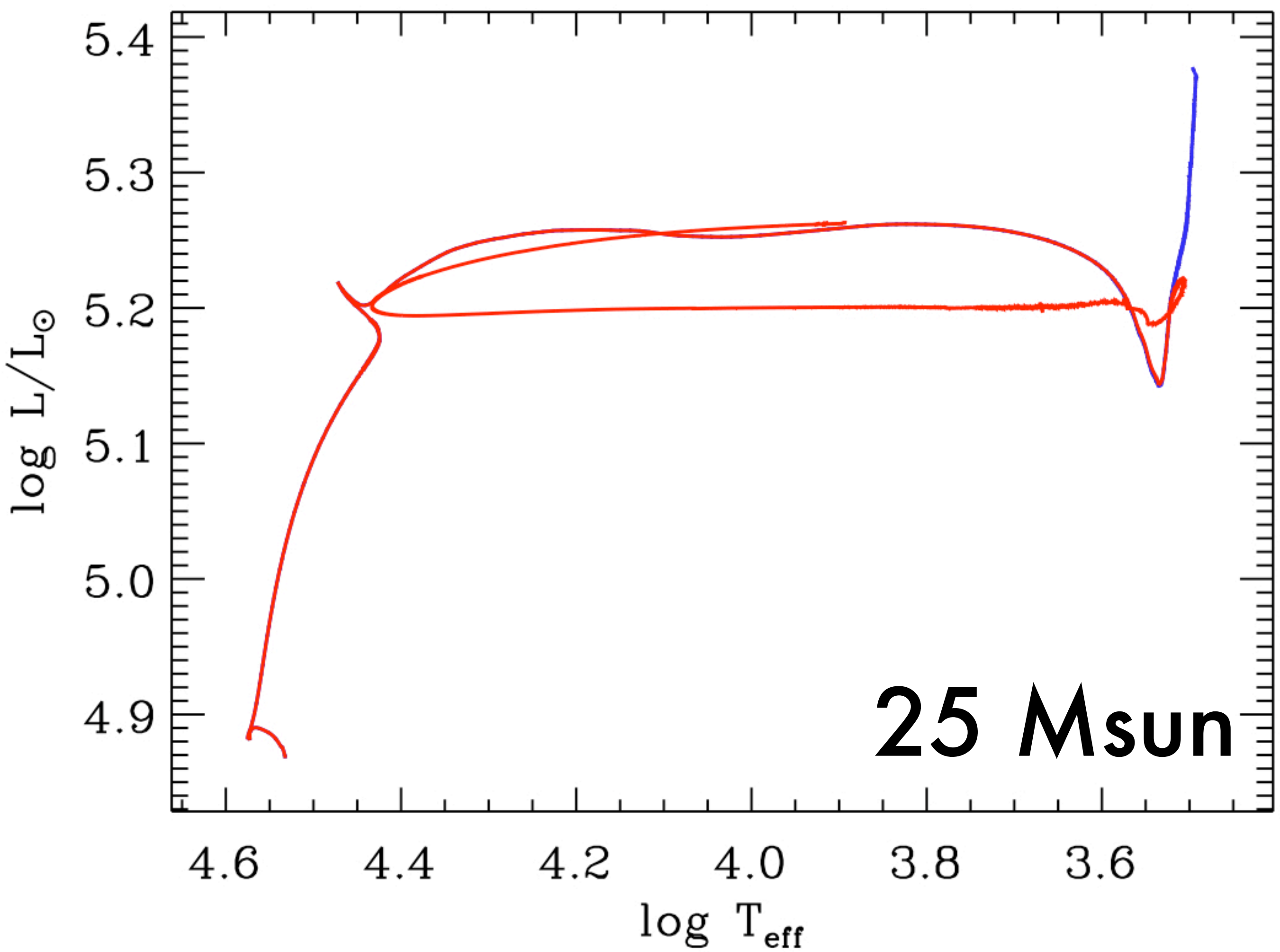
Using the pulsating models (15-40 Msun), we fitted η (the growth-rate of pulsation) as function of the stellar parameters.

Then we assumed that mass loss is enhanced by pulsation:

$$\dot{M} = \dot{M}_0 \eta^{\alpha}$$







25Msun Hydrostatic Model with pulsationally enhanced massloss

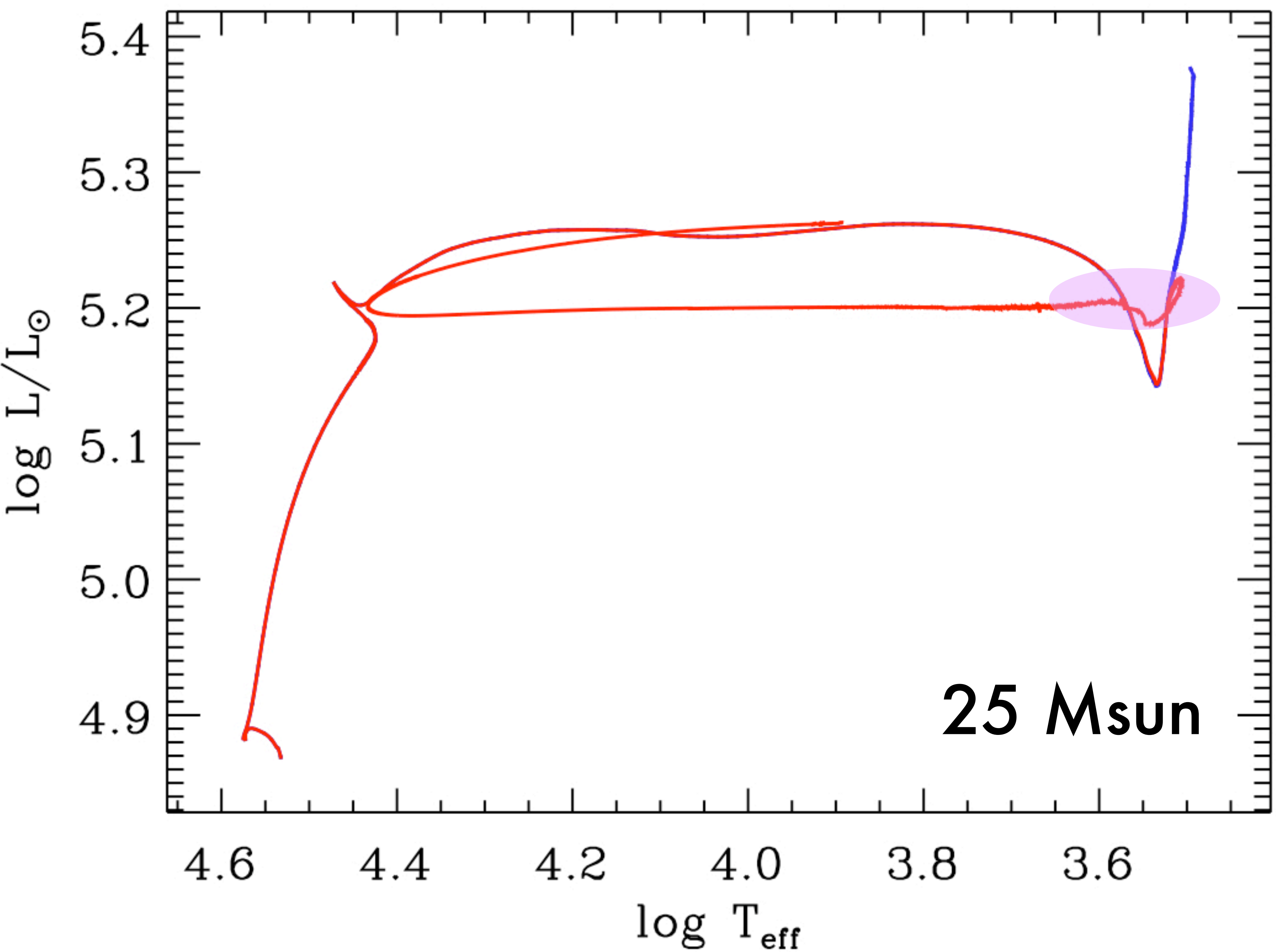
Basic Assumption: $\dot{M} \sim \eta^{\alpha}$ with alpha > 0

- L/M increases with mass loss, hence eta increases. This results in a **Runaway effect!**

- When T> 5000K the **mass loss rate suddenly decreases**

- The "**superwind phase**" would occur later in less massive star.

SN impostor? LBV-like eruption?



Since L/M decreases with mass loss, the star becomes very unstable to pulsation (10-20 times higher growth rate than in a normal RSG).

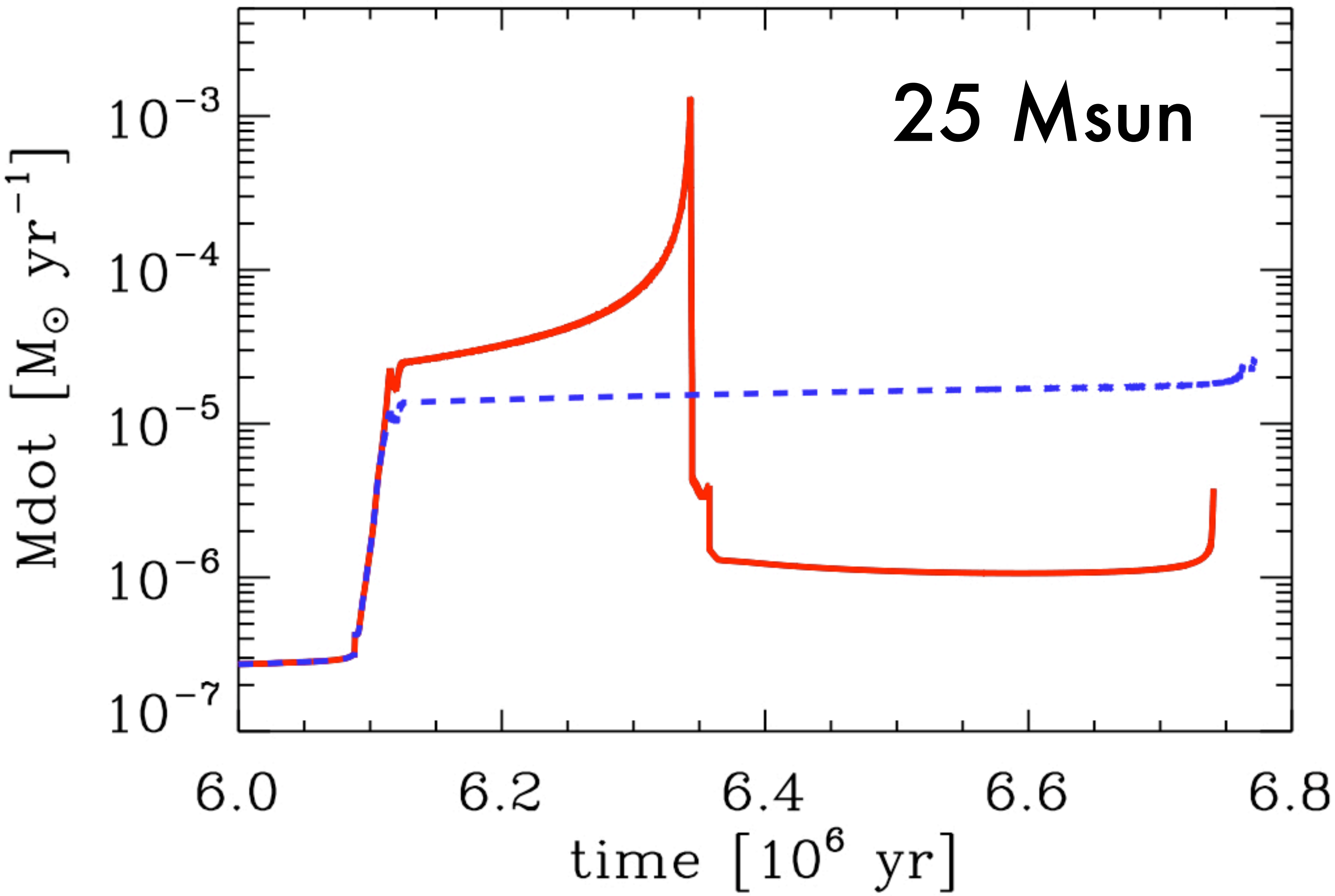
E ~ L * dt
dt ~ P ~ a few years
=> E ~ 10^{46} -10^{47} erg

SN Type IIn

- Depending on **M_{ini}** strong pulsation sets in from early core He burning to C exhaustion.

- Eruption-like event occurs **~1000 yrs** before core collapse in a 20 M_{sun}

- Such event would be observed as a **Type IIn SN**



SN Progenitors

A new scenario for SN progenitors:

Type	M_{ini}
IIp	$9 \sim 19\ M_{sun}$
IIn	$19 \sim 21\ M_{sun}$
IIL/IIb	$21 \sim 30\ M_{sun}$
Ib/c	$>\sim 30\ M_{sun}$

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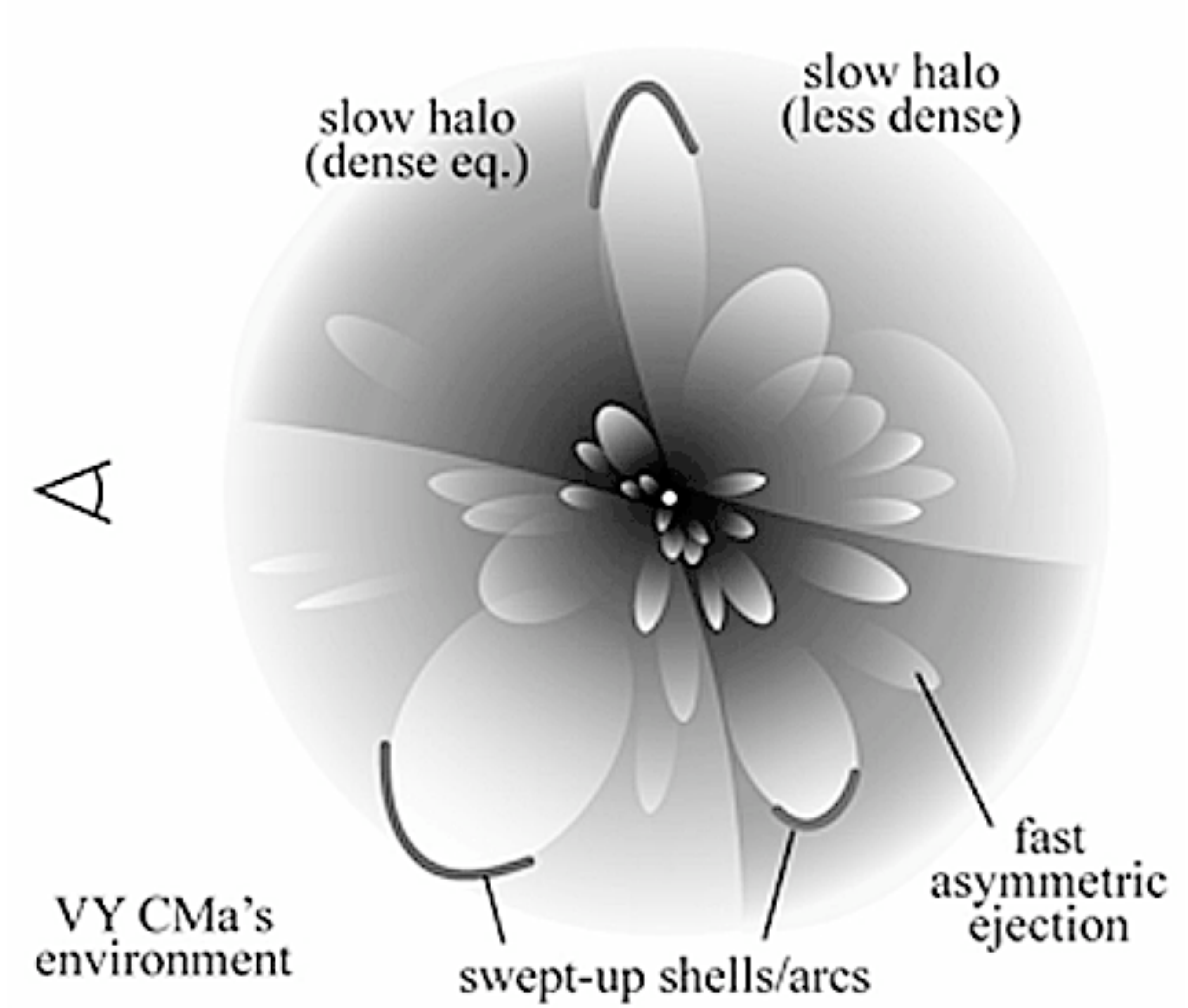
Preliminary!

VY CMa: an extreme RSG

If VY CMa were to explode now, it would results in a Type IIn (Smith et al. 2009)



Smith et al. (2009)

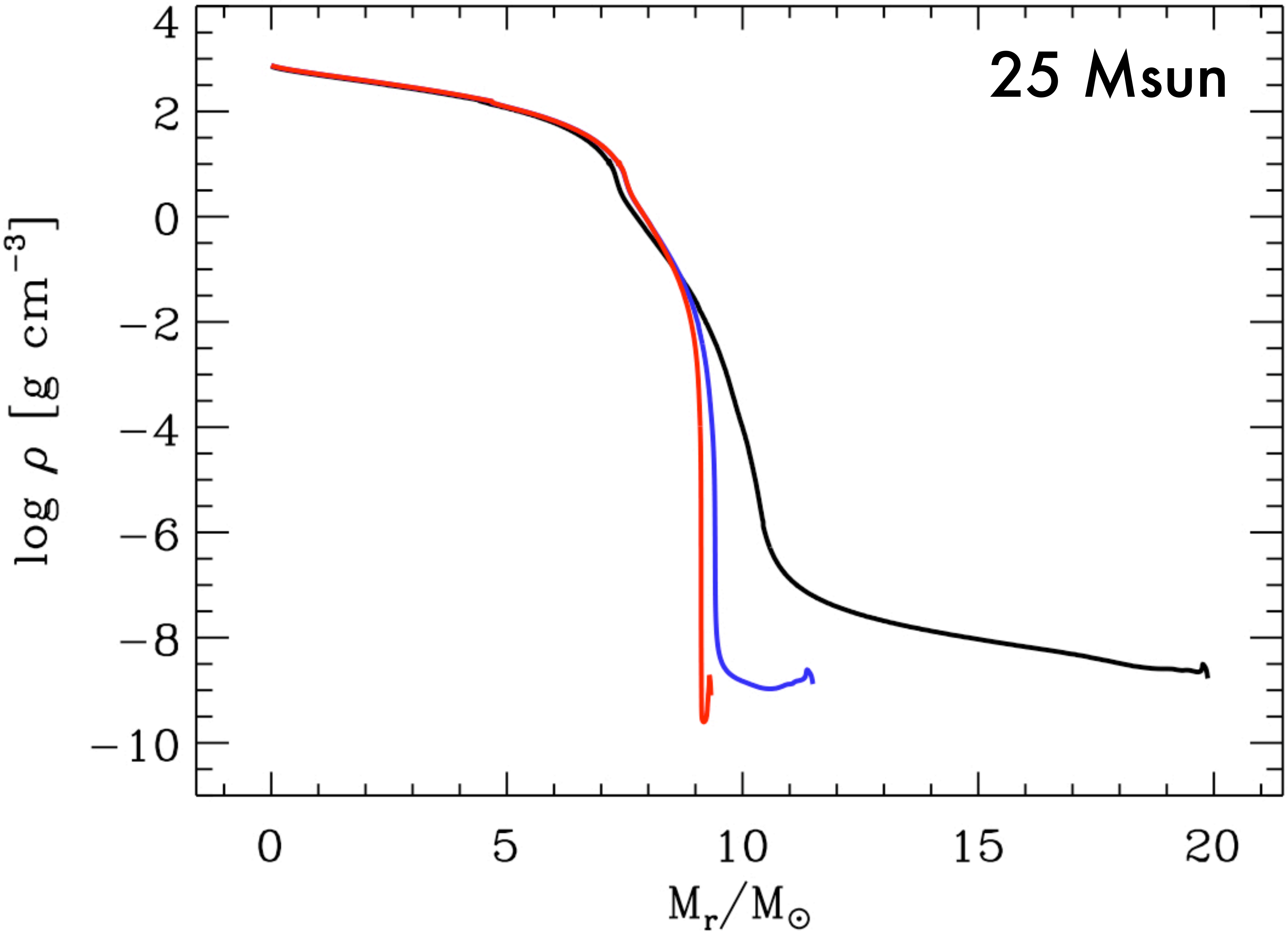
Credit: Nasa/Humphrey

Conclusions

- Strong **pulsation in RSG** is expected for $M_{ini} > \sim 17\ M_{sun}$
- If pulsation causes mass loss enhancement, a **runaway increase, followed by a sudden decrease in the mass loss rate** is predicted
- This might explain the recent observational evidence that **no SN Type IIp progenitor has $\mathbf{M_{ini} > 17\ M_{sun}}$**
- Some **SN type IIn** may be produced by relatively low mass stars ($\sim 20\ M_{sun}$)

OBRIGADO!

Density structure



Pulsation in RSGs is caused by partial ionization of hydrogen for T < 10000 K

$$\kappa \propto \rho^{n} T^{-s}$$

$$\frac{\delta L_r}{L_r} \approx -\left(\frac{4/3+n}{\Gamma_3 - 1}\right)\frac{\delta T}{T} + (s+4)\frac{\delta T}{T}$$

$$\frac{\delta L_r}{L_r} \approx 4\frac{\delta T}{T}$$

For a completely ionized region

$\Gamma_3 = 5/3$, s~3.5, n~1

Compression and heating lead to more leakage of radiation.
=> Stable against pulsational instability

$$\frac{\delta L_r}{L_r} \approx -C\frac{\delta T}{T}$$

For a partially ionized region

Γ_3 --> 1, s < 0,

Compression and heating lead to more trapping of radiation
=> Unstable to pulsational instability

Some literature

Levesque et al. (2007): variable RSG in the magellanic clouds (P~ year)
Lobel et al. (2003): the yellow hypergiant rho Cas (P~1.7 yrs)
Smith et al. (2009): RSG as potential Type IIn progenitors (VY CMa)
Vink & Kotak: variable CSM around SNe
periodic modulation in the radio flux of SN2001ig, SN2003bg, SN1979C and SN1998bw (P~few/hundreds years)

+ many sign of variability for RSGs